

## Is DEA useful in the regulation of water utilities? A dynamic efficiency evaluation

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**IS DEA USEFUL IN THE REGULATION OF WATER UTILITIES? A DYNAMIC  
EFFICIENCY EVALUATION**

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# IS DEA USEFUL IN THE REGULATION OF WATER UTILITIES? A DYNAMIC EFFICIENCY EVALUATION (A DYNAMIC EFFICIENCY EVALUATION OF WATER UTILITIES)

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**Abstract:** The discussion about public utilities efficiency and its management has become increasingly important in the last decades. We focus on the distribution of water, which is one of the most important natural resources (Marshall, 1879). This research shows the relationship between efficiency and institutional factors such as management system. For this purpose, we have data about some Spanish water utilities under different provision systems, during the 1985-2000 period. Using Data Envelopment Analysis (DEA), we estimate potential cost savings in this context. We will extend the results obtained by Thanassoulis (2000), in attempt to guide the regulation of this sector.

**Keywords:** water supply, efficiency, Data Envelopment Analysis, price regulation

**JEL Classification:** D24, Q25, Q28

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**1.- INTRODUCTION**

Throughout the ages, water has been considered one of the most important natural resources that has made the development of civilization possible [Marshall, (1879); Gibbons (1986)]. Water resource availability has conditioned the location and growth of towns and contributed towards public health improvements. Its significance combined with its relative scarcity have made water the object of several conflicts. Its allocation among alternative uses, in order to attain high social welfare levels, has become one of more frequently discussed issues in the field of the economic theory of natural resources.

In this research, our aim is to make a contribution towards improving water allocation by studying the productive process. In particular, we have focused on analysing potential cost savings corresponding to the final stage of water distribution, with a view to be applied to price regulation in this sector, and introduce incentives to get productivity improvements. In this sense, we base our approach on that followed by Thanassoulis (2000, a, b), using Data Envelopment Analysis methodology (DEA) and including some changes in the basic model in order to adapt it to the Spanish case. Scarcity problems which water suppliers in Spain have to face have motivated the inclusion of initial endowments of water resource as a non-controllable input for suppliers, as it is a factor that has conditioned the service in several Spanish regions.

The study is structured as follows. First of all, a price regulation rule has been proposed, thereby justifying the usefulness of the DEA technique. Next, the

methodology applied to obtain information about the relative productive performance of entities is described. In the two following sections, we describe the data and variables used and the productive units considered in the DEA analysis. In the next section, we present the main results of this research. Finally, the paper ends with some concluding remarks.

## **2.- A PROPOSAL FOR PUBLIC REGULATION OF WATER RESOURCES IN SPANISH MUNICIPALITIES**

Regulation takes place when a public entity defines a behaviour framework for different economic agents (households, firms), establishing several obligatory constraints. Some services, such as water, electricity or gas supply, are habitual focuses of regulatory activity. In particular, quality and price restrictions are frequent in water distribution services. In this study we want to emphasize price regulation, because of the importance that pricing policies have in this context (OECD, 2001).

Spanish legislation defines urban water distribution as a public utility that has to be provided by municipalities. Prices of this service are subject to a two-step approval process, in the context of an authorized tariff regime. First of all, prices are provisionally approved by the municipality, with the Autonomous Regions, through its Price Commissions<sup>1</sup>, providing the definitive approval of the prices proposed by local governments. In this process, price structure is not conditioned, and there are no explicit rules that limit the evolution of tariffs.

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This latter fact generates important differences in Spanish price levels [MMA (1998); INE (1999)], which are never justified strictly by cost or other supply conditions. In this sense, it was shown that the expectations of a cheap resource availability and the subventions linked to water prices are the source of current problems, leading to insufficient incentives for promoting water savings (MMA, 1998). In our country, water bill amount to a very small proportion of the total households' expenditure, so that fact reduces the effectiveness of prices as a mechanism to manage water demands in urban contexts (Martinez-Españeira and Nauges, 2004). To address this situation, the European Directive 2000/60/CE establishes the framework to guide water policies for EEC members, with a focus on cost recovery. Its basic objective consists of avoiding highly subsidized, below-cost pricing caused by political reasons.

In a parallel way of water tariff design (OECD, 1987;1999), it would be interesting to study some rule that set global limits on price evolution. These kinds of restrictions, called *price-cap* regulation, have been defended because of its superiority with respect to other regulatory methods, such as *rate-of-return* or *cost-plus* regulation [Schmalensee (1989); Liston (1993)]. The best-known example in this context is *RPI - X* regulation, where *RPI* is a retail price index and *X* is a factor connected with supplier productivity or efficiency. The flexibility of this rule has been highlighted in that price ceilings are defined for a bundle of the firm's products and /or services.

In this research, framed as it is in a public management environment, we have chosen a specification of this methodology which depends on the specific aid

that supplier is searching for<sup>2</sup>. The features of units evaluated in this study lead us to consider the hypothesis that those units are social welfare-maximizing, or, even, vote-maximizing. Under this assumption, price ceilings would have to be fixed in minimum terms, to avoid reducing prices too sharply (Bös, 1994). In this case, price variation,  $P$ , could not be lower than the following limit:

$$P \geq RPI - X \quad (1)$$

According to the preceding expression, more efficient entities face a lower limit, and would have to raise prices less than inefficient ones. Incentives to save costs are clear. Suppliers would try to increase efficiency, and consequently the  $X$  factor, thereby achieving a lower ceiling in the next period.

The  $X$ -index can be exogenously given as far as the regulated entity is concerned, in which case we speak of a *political regulation*, or it can be fixed in an endogenous manner, which can be referred to as *productivity-related regulation*. Under both variants, the regulator provides incentives for improving supplier performance, and it would be necessary to evaluate the temporal evolution of each productive unit efficiency. This fact introduces a role for Data Envelopment Analysis (DEA) as an instrument with which productivity performance can be analysed, and which is described in the next section.

### 3.- USING DEA IN THE CONTEXT OF WATER DISTRIBUTION

As it was noted in the introduction, the nature of this research implies, as an intermediate step, the evaluation of potential cost savings of entities that supply water in an urban context in order to define a valid regulatory approach. We have used DEA methodology, in accordance with several studies applied to water services [Aida et al. (1998); Thanassoulis (2000, a; b)].

This is a non-parametric methodology, in that unlike most econometric methods, no parameters specifying a particular functional form need to be calculated. First developed by Charnes et al. (1978), it is a general linear programming-based technique to evaluate productive efficiency. Assuming homogeneous productive units, a frontier formed by efficient units is designed. In the primal optimization programme, and considering a sector with  $K$  suppliers, which produce  $s$  outputs denoted by  $y$ , using  $m$  inputs denoted by  $x$ , the efficiency of productive unit  $k_0$  would require solving the following constrained programme:

$$\begin{aligned}
 h_{k_0} = & \text{Máx.} \quad \sum_{j=1}^s u_j y_{jk} & (2) \\
 \text{s.a.} \quad & \sum_{i=1}^m v_i x_{ik_0} = 1 & i=1, \dots, m \\
 & \sum_{j=1}^s u_j y_{jk} - \sum_{i=1}^m v_i x_{ij} \leq 0 & j=1, \dots, s \\
 & u_j \geq \varepsilon, \quad v_i \geq \varepsilon, & k = 1, \dots, k_0, \dots, K
 \end{aligned}$$



With regard to the remaining notation,  $u_r$  and  $v_j$  denote, respectively, the weights to be assigned to outputs and inputs,  $\varepsilon$  is a non-Archimedean infinitesimal, while  $h_{k_0}$  is the efficiency index of the  $k_0$  supplier. As can be seen, the preceding programme is orientated towards output maximization, under constant returns to scale (CRS).

This basic model has been adapted by Thanassoulis (2000, a), who estimated potential cost savings in the specific context of the British water distribution sector. He used DEA methodology as an instrument, transforming the previous model (output maximization orientated) into an alternative version which made the interpretation of the model more transparent and whose final result is the calculation of the cost savings of the companies. Specifically, Thanassoulis obtained the following expression:

$$EFF\ x_{1k0} = UC^*_{y1}\ y_{1k0} + UC^*_{y2}\ y_{2k0} + UC^*_{y3}\ y_{3k0} \quad (3)$$

where  $x_1$  is the only input considered in his study,  $y_1$ ,  $y_2$  and  $y_3$  are three output categories produced by the supplier,  $EFF$  is the potential cost objective that must be reached by each supplier and  $UC^*_{y1,2,3}$  are the optimal weights generated endogenously by adapting DEA programming and which are equivalent to the unitary cost of each output. In this sense, for those companies that verify  $EFF\ x_{1k0} < x_{1k0}$ , their potential cost savings would be  $(x_{1k0} - EFF\ x_{1k0})$ .

In our opinion, and considering that our final aim is the measurement of potential cost savings of the regulated entities, the adaptation of the basic DEA

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model orientated to maximize output proposed by the author does not contribute to improving the transparency of the technique used. The reason is that under the constant returns to scale defended by the author the efficiency indexes assigned to each supplier (which are those which will ultimately generate a measure of potential savings) are the same, independently of the orientation of the DEA model. Instead of the proposed version of adapting the basic model to maximize output, and since the final result is the same, a DEA model orientated to input minimization seems to be more appropriate as it has a direct interpretation in terms of potential cost savings.

Following this reasoning, in the current study we use the original version of the DEA programme orientated to input minimization in order to detect cost savings for each municipality and year considered. These savings will be used to implement the proposal for price regulation to be finally applied in each municipality.

However, it is necessary to specify some features that have to be taken into account in the Spanish case, so we have proposed some modifications on the basis of the preceding model. For example, in several Spanish regions suppliers have to face relative scarcity of water resources. We can say that there are high pressures on water in Spain, to the extent that it appears at the top of a ranking corresponding to a group of European countries (OECD, 1997). Economic water shortage is talked about, caused on the one hand by different endowments (heterogeneous climates), and on the other hand as a consequence of the impact of economic activity and socio-cultural features. Sometimes, this leads to the

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3 application of rationing policies. Thus, during drought periods, suppliers could  
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5 distribute lower output than in periods without restrictions in order to adjust  
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7 available resources to existing demands.  
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12 With a view to including in our analysis the effect of this technological  
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14 characteristic, we have incorporated the rainfall of each geographical area and  
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16 period, which would be defined as a non-controllable input by suppliers. In DEA  
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18 literature, the importance of giving a differentiated analytical processing to these  
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20 non-controllable inputs evaluated is accepted. Otherwise, the final results would  
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22 be biased, thereby invalidating the information obtained in the analysis<sup>3</sup>. In light  
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24 of this, two alternative models (M1 and M2) have been considered, where in the  
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26 second one (M2) a non-controllable input has been included in accordance with  
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28 the methodological guidelines existing in the literature for this kind of variable  
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30 (Banker and Morey, 1986).  
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39 The definitive method used to calculate potential costs savings of a specific period  
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41 and supplier has consisted of carrying out a separate DEA analysis in each  
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43 municipality, oriented to input maximization. As productive units to be compared,  
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45 we have used the results of the same municipality during the period analysed.  
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47 Moreover, in order to check for its effects, an alternative version of the basic  
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49 model which includes rainfall as a non-controllable input has been applied.  
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**4.- VARIABLES**

Having outlined the model which we use to study efficiency, we now turn to a description of the information used in the empirical application. In this section the definition and justification of variables included in the DEA analysis is presented.

The choice of variables is a controversial issue in DEA analysis<sup>4</sup>. We have decided to follow the guidelines proposed by Thanassoulis (2000, a). Once he had settled on a group of variables, he finally connected a single input (operational costs) with a subset of outputs, such as water delivered, the level of properties and the length of mains. In our case, the variables which are included in the efficiency analysis are shown in Table 1:

[INSERT TABLE 1]

In line with the situation described in the previous section, it is desirable to introduce an additional factor into the basic model in order to capture the effect of variables which cannot be controlled by the supplier and which can have an influence in the results. Thus, the density of rainfall taken up in the Hydrographical Basin where each municipality is located is incorporated in order to approximate the scarcity problems of water suppliers.

As can be seen, three outputs have been included. The first one, number of  $m^3$  delivered, is habitual in this context. The remaining output variables (KMNET, POPULATION) are related to the spread of service coverage from a geographical

point of view, and both have an important influence on costs (Thanassoulis, 2000, a).

## 5.- MUNICIPALITIES ANALYSED

With the aim of identifying the evolution of drought periods, and in order to evaluate efficiency trends over time, we use a time series from 1985 to 2000, both years inclusive, for three Spanish municipalities of different characteristics (Seville, Elche and Gijón), whose main features are described below. There are differences in terms of size, climate and socioeconomics aspects, which allow us to check the adaptation of the proposed model to several productive environments.

Seville constitutes the biggest municipality included in the study. Its population density is around 5,000 inhabitants per  $km^2$ . It is located in the south of Spain and is characterized by a continental climate with Atlantic influences, with high temperatures and poor rainfall. Currently, supply is delivered by a local public firm. The Municipal Water Company of Seville (EMASESA) is the organism that supplies the resource in the capital and in some adjacent towns. The progressive incorporation of those towns to the distribution service has made the supply system more complex. According to company sources, these towns had *“five different network systems and singular pumping stations, together with a greater depth than that which was usually set in its basic distribution network (...)”*(EMASESA, 1997, p. 39). The company manages several reservoirs directly, so it does not need to buy water input from external suppliers, except in

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emergency periods. The leakages percentage registered in the network is high, reaching, in average terms for the period considered in this research, around 23%.

Elche is a municipality located in eastern Spain, whose population density is about 600 inhabitants per  $km^2$ . It is made up of 22 towns, with different characteristics, including village settlements and tourist areas. However, 90% of the population is concentrated in the city of Elche. It is in an arid area with a concentration of rainfall in autumn. The water supply had been directly delivered by the municipal administration without the mediation of any company or organism. Water input is bought entirely from external suppliers. The Association of Taibilla Channels is the main source (supplying 80%-90%, depending on the period considered), followed by the Villena Channel (10%-20%). Average leakages during the period were about 18%.

The third and last municipality analysed in our study is Gijón, located in the north of Spain, with a population density close to 1,500 inhabitants per  $km^2$ . It is made up of 105 towns/villages, with a wide geographical dispersion. Again, 95% of the inhabitants are located in the city of Gijón, and the remaining population is spread out over the other villages. The climate is characterized by mild temperatures, precipitations and seasonal differences. A public firm supplies water in the municipality (EMA). The EMA was constituted in 1965 with the principal objective of resolving the deficiencies in the system at that time. Nowadays, these shortcomings have been eradicated, and the leakages percentage has been under 15% in recent years. Part of the supply needs are covered by water from reservoirs which are managed by the Consortium of Water Supply and

Sewerage in the central area of Asturias (CADASA). This association was created to deal with scarcity problems in the region, which had a high population density together with a notable level of industrialization. Currently, it supplies around the 50% of the municipality consumption.

Finally, in Table 2 we show statistics of the variables defined above for each municipality, and it is possible to see clear divergences among them.

[INSERT TABLE 2]

## 6.- RESULTS

The quantitative results from applying the models described in section 3 (M1; M2) appear in the Appendix. This information is shown in Graphs 1 to 3, with comments immediately after in order to facilitate the visual interpretation of the evolution of performance corresponding to each municipality.

With regard to global results, in the three cases analysed it was verified that the model M2 (which includes the effect of the non-controllable input) leads to higher or equal efficiency indexes than those obtained under the model M1 (which does not include that effect). This is a result inherent in the methodology used and its significance in this case is not a very important issue since, as will be shown below, the important thing is to analyse the temporal evolution of efficiency indexes in each municipality and any divergence that may arise between the results of models M1 and M2.

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Studying the three graphs, it is possible to see differences across municipalities as to the evolution of efficiency in water distribution service over time. This is an especially interesting result because it is a direct consequence of the feature (mentioned when the Spanish sector was described) that there are large variations between the conditions and results of Spanish regions with regard to water supply, caused by differences in performance and in which economic and politic aspects intermingle. For this reason, it is more appropriate to comment on the results separately for each municipality, since, in the Spanish case, there are not common features with regard to supply conditions.

[INSERT GRAPH 1]

Beginning with Seville, we can observe two different trends. At the beginning of the time series, performance is steady and, in relative terms, positive. This pattern is broken from the year 1996, when productive efficiency becomes notably worse. Low efficiency levels remain until the last year of our sample. However, the use of model M2 shows that, in the second lower-efficiency stage (1996-2000), the year 1998 is an exception, showing that bad results are attributable to the effect of climatic conditions and not to the poor management of the supplier, as can be deduced from the recuperation of the M2 index for that year.

[INSERT GRAPH 2]



With regard to the municipality of Elche, the most peculiar result is that climatic conditions have no effect on productive efficiency. As a consequence, the results of the models M1 and M2 are the same. This is probably explained because the fact that this municipality has got to adapt supply conditions to climatic fluctuations. Confirming this idea, the local authority alluded that it was not necessary to interrupt water supply, despite precarious climatic conditions, because of the existence of adequate infrastructures to face up to this kind of situations. Moreover, and in relation to evolution over time, an improvement of productive efficiency (with ups and downs) can be observed until the year 1995, after which the results become stabilized at lower levels than in that year but much higher than those in initial years.

Finally, with respect to Gijón, we find again a different evolution from the previous municipalities. In this case, and after some initial years in which the results are very good, we can see a sharp reduction of productive efficiency which starts in 1988 and touches bottom in 1991. From this year, a progressive recovery is initiated, levelling off over the later years. In this municipality, as in the case of Seville, climatology has an huge effect. In particular, if we take into account its influence, the pronounced decreasing of efficiency in the intervening years is held up, so an adverse climatology would explain the bad results obtained in 1988 and 1990. Likewise, the inclusion of climatic influence allows us to observe that the recovery of efficiency in the latest years continues until the year 2000, with similar levels to those obtained in initial years.

[INSERT GRAPH 3]

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After obtaining the results of efficiency in the three municipalities (which are linked to potential costs savings that could be achieved in each case), we would be able to connect those results with price regulation in the sector. In order to guide the evolution of future tariffs, the regulator could have an efficiency objective (*X-factor*), based on average efficiency over the period analysed (or another descriptive indicator) for each municipality, calculating as a expected deviation with respect to that average. The supplier would try to achieve efficiency improvements in order to reduce the ceiling on pricing. In this way, the public regulator gets to provide incentives for saving costs.

**7.- CONCLUSIONS**

In developing countries, the attention paid to the regulation of provision (and production) conditions of the water supply service has increased in recent years. This study has been focused on the regulation of water prices in order to motivate suppliers to cut costs. For this purpose, a rule has been proposed to guide price evolution, based on *price-cap* regulation. The main objective of that instrument will be to provide public authorities an instrument that allows them to set prices according to economic rather than political criteria.

A prior step to setting water supply tariffs has been the analysis of the productive efficiency of suppliers in previous years, or to be more accurate, the measurement of the potential cost savings that they would have been able to achieve if their performance had been the best possible. The DEA methodology is

a useful instrument to implement this step. In this research, two variants of the method have been applied, depending on the inclusion (or not) of a non-controllable input which shows differences in initial water resource endowments in the mathematical programme.

The methodology proposed has been applied to three Spanish municipalities of different characteristics, analysing the evolution of their efficiency during the period 1985-2000. In Spain, there are divergences between water supply conditions across territories, a fact that is clear in light of the implausible evolution that the DEA results for each municipality show. Thus, the *price-cap* proposed must be objective, in order to avoid political interferences, and flexible, to allow its adaptation to the specific conditions of water supply in each municipality or area considered.

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## APPENDIX

## Efficiency rankings: evolution over time

YEAR	SEVILLE		ELCHE		GIJÓN	
	M1	M2	M1	M2	M1	M2
1985	100.00	100.00	68.87	68.87	100.00	100.00
1986	93.07	96.11	69.72	69.72	100.00	100.00
1987	95.73	95.73	72.80	72.80	99.80	99.80
1988	96.00	100.00	79.96	79.96	97.80	100.00
1989	95.05	95.05	80.75	80.75	88.39	100.00
1990	93.80	100.00	70.42	70.42	82.27	100.00
1991	97.18	100.00	88.36	88.36	65.78	73.50
1992	94.82	97.68	81.18	81.18	78.27	79.83
1993	91.70	91.72	75.17	75.17	73.81	75.91
1994	99.97	100.00	85.30	85.30	76.43	80.86
1995	100.00	100.00	100.00	100.00	78.78	81.35
1996	87.18	87.18	82.00	82.00	82.55	85.82
1997	78.07	78.07	89.05	89.05	85.18	94.38
1998	80.66	100.00	88.54	88.54	85.20	100.00
1999	80.61	83.87	85.64	85.64	86.36	96.04
2000	85.50	85.50	84.94	84.94	84.32	92.02
AVERAGE	91.83	94.43	81.42	81.42	85.31	91.22

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TABLES AND GRAPHS

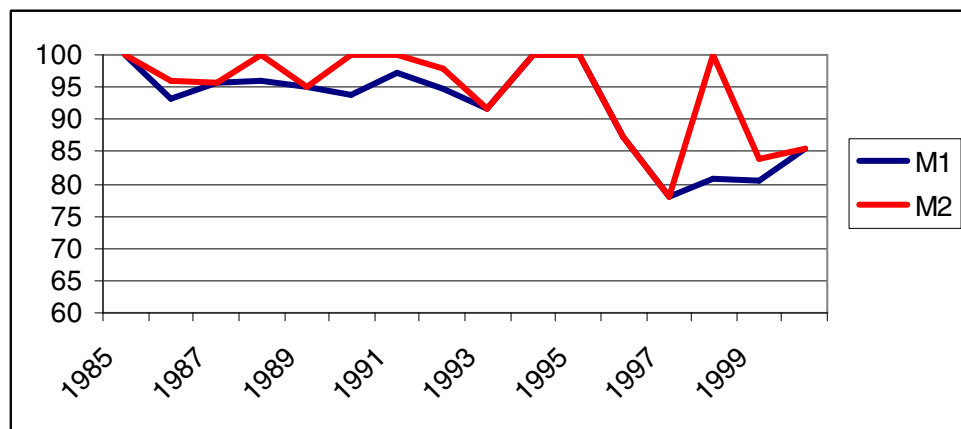
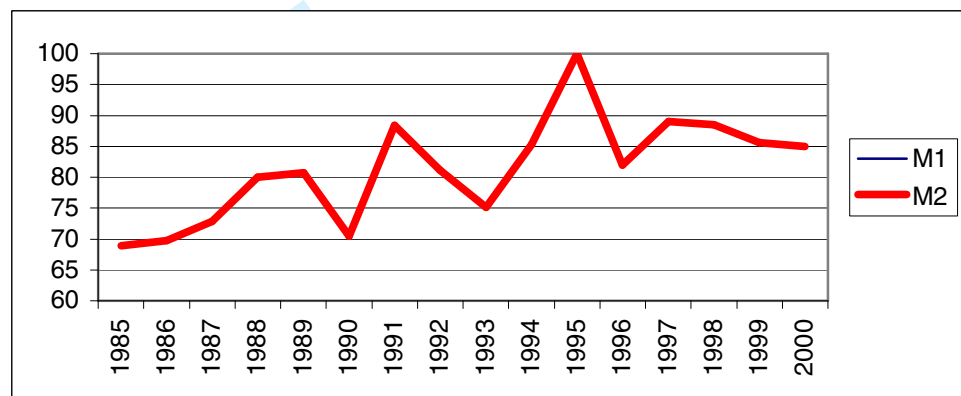
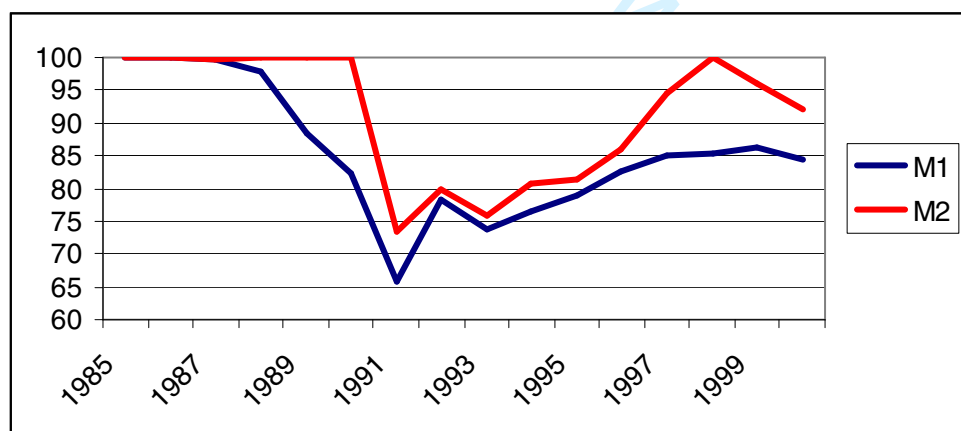
Table 1. Input-output variables in water distribution

Variable	Definition
<b>OUTPUTS</b>	
M3DEL	Water delivered ( $m^3$ )
KMNET	Length of mains ( $Km$ )
POPULATION	Population supplied (number of inhabitants)
<b>INPUTS</b>	
<b>Controllable:</b> COSTOP	Operational costs (2001 )
<b>Non-controllable (M2):</b> RAINFALL	Density of rainfall ( $l$ per $m^2$ )

Table 2. Descriptive statistics of variables

	SEVILLE		ELCHE		GIJÓN	
	mean	stan.dev.	mean	stan.dev.	mean	stan.dev.
<b>M3SUM</b>	90,368,750.0	9,513,619.6	12,864,826.2	1,679,528.8	22,622,792.3	1,670,654.3
<b>KMNET</b>	2,891.6	779.8	519.9	35.1	864.4	109.6
<b>POPULATION</b>	1,120,888.0	115,793.0	186,855.0	6,756.0	264,014.0	4,110.0
<b>COSTOP</b>	47,889,353.5	8,919,579.0	6,150,437.0	473770.6	7,503,024.9	1,412,952.1
<b>RAINFALL</b>	575.5	197.9	455.8	118.9	1,321.9	141.5



**Graph 1. Evolution of productive performance in the municipality of *Seville*****Graph 2. Evolution of productive performance in the municipality of *Elche*****Graph 3. Evolution of productive performance in the municipality of *Gijón***

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**ENDNOTES**

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<sup>1</sup> Price Commissions are very heterogeneous organizations. Several agents take part in the price authorization process, such as members of the Regional administration, the water sector or consumer organizations.

<sup>2</sup> Price-cap regulation could be proposed as a minimum or maximum ceiling, depending on the objective set by the supplier. For more details, see Bös (1994).

<sup>3</sup> See, for example, Charnes et al. (1980), McCarty and Yaisawarng (1993), Ruggiero (1998) or Muñiz (2002).

<sup>4</sup> For specific details, see Lewin et al. (1982), Charnes et al. (1985) o Smith and Mayston (1987).